Renewable and Sustainable Energy Reviews 15 (2011) 2222–2231

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Territorial level for biofuel production—Case study of an Italian region

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ARTICLE INFO

Article history:
Received 22 November 2010
Accepted 27 January 2011

Keywords:
Bioenergy
Residual biomass
BTL diesel
Regional scale

ABSTRACT

An analysis of the biofuel production chain suggests that adapting and optimizing the whole system to an appropriate scale based on the availability of agricultural and/or agro-industrial biomass feedstock is needed. This study of the potential use of these biomass materials is carried out on a regional scale and, in particular, in Apulia, a region in south Italy with a high agricultural vocation. The aims of this paper are to identify the real availability of the residual biomass (particularly lignocellulosic), and form a hypothesis regarding launching new production chains (from biomass to diesel) on a regional scale with appropriate localization in the Apulia territory. According to the methodology (adapted from the European Directive 2009/28/EC on renewable energy sources), the greenhouse gas savings due to the replacement of a share of fossil diesel with BTL diesel produced from inland biomass are evaluated as well. A hypothesis regarding the appropriate scale and localization of BTL plant together with relative costs are presented in the results and discussion section. The conclusion section provides perspectives regarding the BTL diesel and bioenergy system, and the creation of an agro-energy district in the Apulia region.

Contents

1. Introduction

The political strategy of the European institutions (Directive 2009/28/EC) [1] regarding the production and use of biofuels provides a boost toward the study of new and complementary energy options. The most relevant economic and environmental effects of the energy system can be analysed, allowing for different choices of raw materials.

Biofuels are a feasible tool for achieving the European Union (EU) environmental policy on the transport sector, and for securing and diversifying the energy supply. However, conventional biofuels [2] or the first-generation biofuels are based on agricultural feedstock, and are insufficient in meeting these policy goals. On the contrary, biofuels from lignocellulosic biomass (second-generation biofuels) could potentially overcome some limitations—for instance, the high costs of raw materials and land availability. Among the several sources for second-generation biofuel production, the residual biomass generated by the agricultural, forest, and agro-industrial sectors is a widespread and abundant material, not classified as waste, and is considered a potential feedstock for fuels.

We underline, however, that one of the main constraints concerning the chain of energy production from residual biomass is

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doi:10.1016/j.rser.2011.02.001

the feedstock supply: these biomass resources are not concentrated (they have a high territorial dispersion), with an inefficient mode of collection. Hence, additional transport and storage systems facilities may be required, consequently increasing costs and reducing the net energy production [3]. This is a critical item and it suggests the development of short or medium production chains, with a distance of 10 km (to a maximum of 60 km) from the collection/storage points to the energy conversion plant. The growth of short chains, however, could be negatively affected by the inability to compete with the longer bioenergy production chains with profitable economies of scale, supplied by cheap imported biomass. As a consequence, a local market of bioenergy (especially biofuels), has not emerged, and the potential economic and environmental advantages of the entire chain have failed to materialize.

In addition, the interaction between agriculture and industry is difficult because these two sectors usually have differing priorities and courses of action counter to each other. It is therefore important to establish an agreement between the sectors with the aim of achieving a common purpose—the creation of bioenergy production districts closely linked to the territory with its own potential for success.

A correct evaluation of potential biomass exploitation and the rationalization of the entire supply, storage, and energy production chain, requires detailed knowledge of the identified region. Thus, the specific area of study for this paper is Apulia, a region in the south of Italy.

The constraints concerning the bioenergy system mentioned earlier, together with the position taken up by the European institutions (see Section 1.1) place the focus on different criteria to determine the production and use of biofuels. Our analysis identifies the following two important criteria: (1) a biomass pathway at the local level for suitable development; and (2) the use of lignocellulosic biomass residues, particularly for diesel production [4]. These two criteria have been applied in the Apulia region to organize the production of biofuel from residual biomass through the creation of short or medium production chains.

The aim of this paper is to analyse the potential of using residual biomass (particularly lignocellulosic) for biomass-to-liquid (BTL) diesel production. A suitable localization of a BTL plant in the Apulia region has been hypothesized, along with the relative environmental benefits on a regional scale from the prospective substitution of fossil diesel consumed in this area with an equal share of BTL diesel produced in loco.

In the following sub-section, the important policy developments at the European level concerning the role of biofuels are examined. In Section 2, the thermo-chemical process of BTL to produce second-generation biofuel from residual biomass is described, with a brief remark about the material and energy balance of the process. Sections 3 and 4 illustrate the methodology utilized and applied for mapping the biomass feedstock in this region. Sections 4.1–4.1.1 estimate the potential of this residual biomass to produce diesel, including identifying the region's greenhouse gas savings. Section 5 covers the results and discussion, and hypothesizes a suitable location for a BTL plant in Apulia on the basis of the data set out in Section 4, including brief remarks about the relative costs. Finally, the conclusion summarises the perspectives regarding the BTL diesel production chain and the creation of an agro-energy district in the Apulia region.

1.1. EU policy developments regarding biofuels

In March 2007, EU leaders committed to raising the share of biofuels in transport from the current level of approximately 2% (according to the EU's original 2003 Directive on the promotion of biofuels) to 10% by 2020, in response to increasing oil prices, a need for an increased energy supply, and environmental concerns. This undertaking was translated into a legal proposal, presented on 23 January 2008 by the Commission, as part of a broader Directive on renewable energies [5].

This draft directive also replied to the many criticisms regarding biofuel production, including the use of food crops for biofuel production, a consequent danger of mass deforestation, a global increase in food prices, and water shortages. The Commission proposal did indeed ban "bad" biofuels, and introduced three sustainability criteria: (1) land with high carbon stocks should not be converted for biofuels production; (2) land with high biodiversity should not be converted for biofuels production; (3) biofuels should achieve a minimum level of greenhouse gas savings (carbon stock losses from land use change would not be included in this calculation).

These important concerns regarding biofuels production proved insufficient for both the European Parliament's Environment Committee and Parliament's Industry and Energy Committee. They confirmed the 10% Commission's target by 2020, and also decided to set an interim target of 5% by 2015. Moreover, they specified that at least 20% of the 2015 and 40% of the 2020 targets must be met by the use of electricity or hydrogen from renewable sources, biogas, or transport fuels of a "second generation," made by lignocellulosic biomass, waste, or algae. This means that only 4% (by 2015) and 6% (by 2020) of the total road transport energy use could come from traditional "first generation" biofuels.

The Parliament's Industry and Energy Committee was also demanding that, before 2015, a full review of the whole EU biofuel promotion policy and its social and environmental impacts should be carried out to determine whether the targets need revising. Moreover, stricter sustainability criteria in terms of high greenhouse gas savings have been added: initially, the biofuels must save at least 45% of carbon emissions compared to fossil fuels (the Commission had proposed a saving of 35%) and, from 2015 onward, these savings must be at least 60% [6].

The European Economic and Social Committee has paid attention to the previous issues as well. The Committee considers that the current technologies for this sector demand a very high consumption of energy, water, and land, and that it is essential to secure biofuels using "zero-mile" domestic agricultural products for optimizing the fight against pollution [7]. The feedstock should not be transported from distant countries, consuming fossil fuels in the process. The difficulties in efficiently producing energy from agro-food residues arise from their widespread distribution, requiring costly transportation to processing centres, and from significant water content of the residues, requiring high volumes for processing. For these reasons, biomass of this kind should preferably be processed in situ. Therefore, it is important to point to the fact that the production of biofuels, even if it is a sector of national importance requiring reliable centralized planning, could only have real development possibilities if it is territorially closely linked.

Finally, on 17 December 2008 and 23 April 2009 [1], the European Parliament voted overwhelmingly in favour of the legislation package of energy and climate change, and translated the Commission proposal of January 2008 into law. An agreement was reached regarding three targets for the year 2020: a 20% reduction in greenhouse gas emissions, a 20% improvement in energy efficiency, and a 20% target for the overall share of energy from renewable sources. Mitigating many of the demands of the European Parliament's Industry and Energy Committee, the main changes introduced by the European Parliament are the following:

1. The share, at least 10% in 2020, of final consumption of energy in transport in each Member State shall be ensured to come from renewable sources, not only from biofuels (Article 3).

2. The smallest share of greenhouse gas emission savings from the use of biofuels and other bio-liquids in comparison with fossil fuels is to be 35%; from 2017 onward, these savings shall be increased to 50%, and after 2017 it shall be 60% for biofuels produced in installations having begun production after 2017 (Article 17).
3. Renewable sources (biofuels included) have to fulfil the sustainability criteria in order for land use changes to occur, and the use of raw materials obtained from land with high carbon stock (e.g., wetlands or continuously forested areas) to be taken into account, binding it to restrictive criteria (Article 17).
4. The biofuels or bio-liquid and/or raw materials for their production shall be in compliance with sustainability criteria, whether produced within the European Union or imported and, in the latter case, a certificate of compliance with these criteria shall be needed (Article 18).
5. For the purpose of demonstrating compliance with the target of 10% of total energy used from renewable sources for all forms of transport (referred to in Article 3), the contribution made by biofuels produced from wastes, residues, non-food cellulosic material, and lignocellulosic material shall be considered to be twice that made by other biofuels (Article 21).
6. A constant monitoring shall be made by the Commission regarding the impact biofuel production may have on food prices (Article 23).

2. Conversion technologies for BTL diesel production from residual biomass

Biomass includes several resources, such as wood and wood residues, agricultural crops and their by-products, waste and by-products from agro-food processing, animal waste, the separately collected biodegradable fraction of industrial and municipal waste, and aquatic plants (algae). Biomass resources can be used for energy production and converted in heat, electricity, and fuels; frequently these energy carriers are co-produced. Regarding the conversion technology for energy purposes, there are four main categories of processes [8–10]:

1. direct combustion (production of heat and/or electricity),
2. thermo-chemical (e.g., pyrolysis, gasification, Fischer–Tropsch synthesis),
3. biochemical (e.g., anaerobic digestion and fermentation),
4. agro-chemical (e.g., sunflower oil extraction or waste cooking oil processing and bio-refining).

The last three conversion technologies are suitable for biofuel production and, among these, the thermo-chemical and agro-chemical processes most suitable for producing diesel. The agro-chemical process refers to biodiesel production from energy crops [11,12] or waste cooking oils [13,14], and NExBTL (next-to-biomass-to-liquid) renewable diesel production through bio-refining, based on the direct hydrogenation of vegetable oil and animal fat [12].

The thermo-chemical process of BTL, a combination of gasification and Fischer–Tropsch synthesis [15], to produce second-generation biofuels is described in this paper. There are several BTL processes, as well as many technologies, but in general the process converts lignocellulosic biomass[1] (particularly woody and herbaceous biomass), first using a gas mixture of carbon monoxide and hydrogen and then in liquid hydrocarbons of variable chain lengths (CxHy), to produce the so-called BTL diesel. The BTL process is illustrated in Fig. 1, and a brief description of a typical BTL process follows.

Table 1
Composition of biosyngas from biomass gasification.

Constituents	% By volume (dry and nitrogen free)
Carbon monoxide	28–36
Hydrogen	22–32
Carbon dioxide	21–30
Methane	8–11
Ethane	2–4

Source: [17].

Pre-treatment. Before gasification, biomass feedstock requires several pre-treatments, such as drying and size reduction. The efficiency of gasification increases with drier biomass; its optimum moisture content being between 10% and 15%

Gasification. After pre-treatment, the biomass is converted into a mixture of hydrogen, carbon monoxide, carbon dioxide, and other compounds (Table 1). Different gasification methods for obtaining syngas are available [18].

The gasification with oxygen as an oxidative medium is surely favourable but, due to its high cost, oxygen enriched air can be an alternative medium [19].

Gas cleaning. No gasification process produces raw syngas that fits the requirements of the catalytic process for obtaining Fischer–Tropsch (FT) diesel, introducing the necessity of gas cleaning. The organic tars, BTX (benzene, toluene, and xylenes), inorganic impurities such as NH_3, HCN, H_2S, COS, and HCl, volatile metals, dust and soot are impurities contained in produced gas which need to be removed.

Reforming, shifting, CO_2 separation. The syngas produced contains H_2, CO, CO_2, CH_4, and other light hydrocarbons. There are several operations that can be carried out to obtain a suitable ratio among these compounds.

The reforming of methane (which is optional) converts it into hydrogen and carbon monoxide, using steam over a nickel catalyst. The syngas produced from the circulating fluidized bed (CFB) process usually has a low H_2:CO ratio (2.1:1), so gas shifting is done to increase this ratio and to convert, using steam, CO into H_2 and CO_2.

After reforming or shifting, the amount of carbon dioxide is increased and therefore has to be removed by the use of solvents [10,22].

FT synthesis. The time conversion in a FT reactor is limited, depending on catalyst type (Ru and Co catalysts are better than Fe), as well as on reactor size and technology used. The reactor product stream contains FT products and un-reacted CO and H_2.

The outputs of the FT process are C_{5+} hydrocarbons, distillate, and wax fractions for further processing. The C_{5-9} fraction is separated from the heavier products, and serves as raw material in the production of green plastics. This fraction cannot be used as green petrol because of the low octane number.

The waxy part (C_{10+}) is selectively put through the hydro cracking in order to increase the output of diesel or kerosene (C_{10-20} fractions), the amount of which is dependent on how the hydro cracking is managed [23]. Table 2 provides the composition and main properties of diesel from fossil sources and BTL diesel.

[1] The lignocellulosic biomass consists mainly of three components: cellulose, hemicellulose, and lignin. Cellulose is a strong molecule formed of long chains of glucose; hemicellulose contains a mix of hexose and pentose sugars, and is easier to break down with heat or chemicals; lignin is responsible for providing the rigidity structure of crops and trees. This biomass can have several combinations of these components, with a range of 40–50% cellulose, 20–40% hemicellulose, and 10–25% lignin [15].

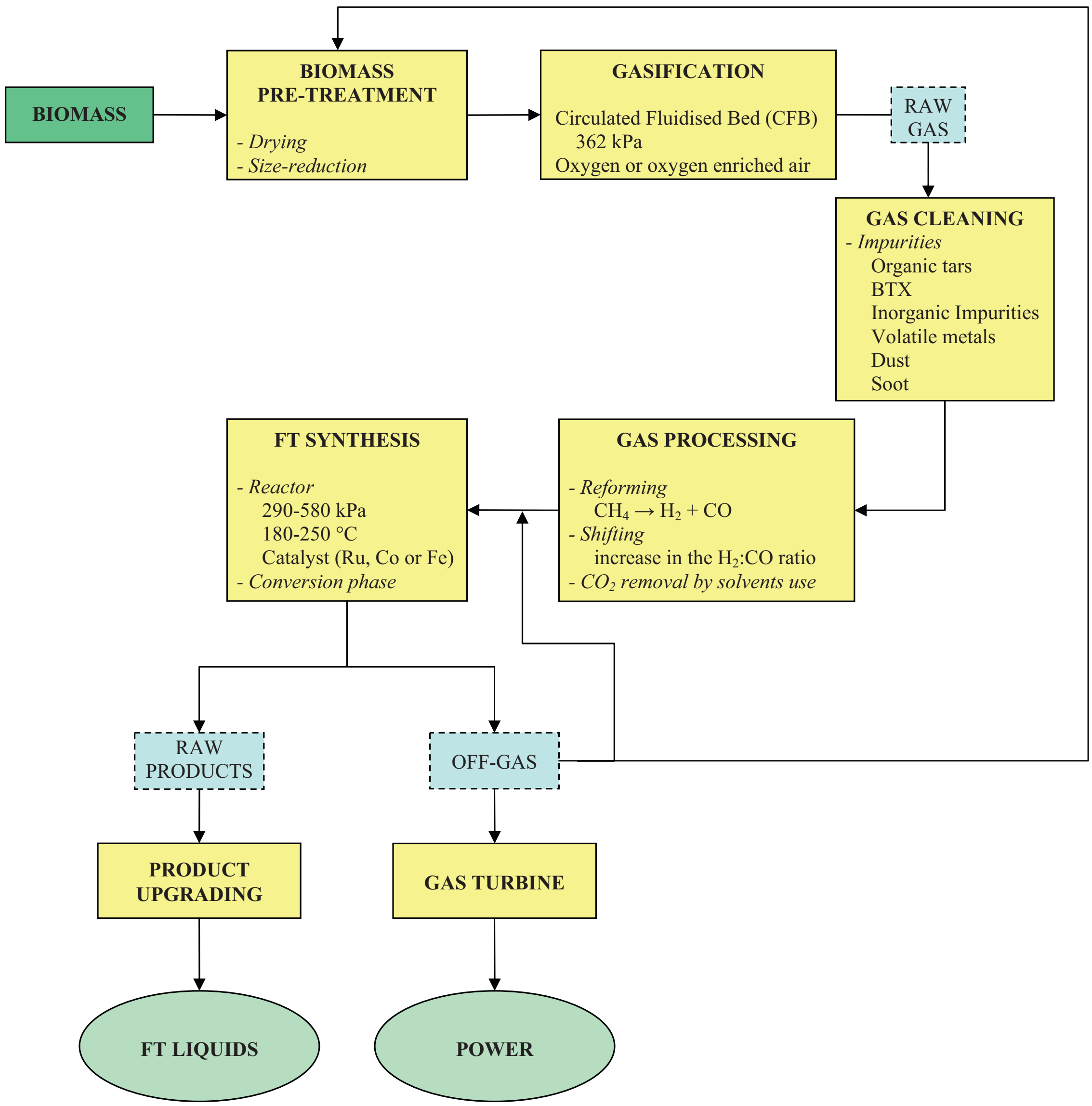

Fig. 1. Schematic flow-chart of BTL process.

Sources: [19–21].

2.1. Energy and material efficiency conversion

The energy efficiency conversion of the whole process of converting biomass into fuel is around 40–45%, and increases to 60–70% if the co-generation production of liquid fuel and electricity is considered [22,25]. The energy consumption in the whole production chain for biofuels (chopping, transporting, and distributing, as well as the conversion process itself) could be calculated by a well-to-wheel (WTW) analysis [26]. This approach generally refers to fuel production, and in recent years has been applied to biofuels as well. The fuel cycle stages, from biomass recovery through to delivery of the fuel to the vehicle, are called well-to-tank (WTT), the use of fuel in vehicles is referred to as tank-to-wheel (TTW), and the entire fuel cycle, as above mentioned, is known as WTW.

Table 3 shows figures related to a WTT analysis. The energy expended to produce 1 MJ of FT diesel from waste wood and farmed wood is 1.19 MJ, much higher than the energy expended for 1 MJ of fossil-derived diesel, which is 0.16 MJ. It has been noted that the latter lower figure is linked with fossil energy only, and in the former figure, the energy supply quotas from fossil energy is 0.07 and 0.06 MJ_{ex}/MJ_{fuel}, respectively, for the generation of FT diesel from waste wood and farmed wood.

During the entire cycle, it appears that the processes of gasification and FT synthesis require more energy (1.08 MJ) than the

Table 2
Main properties of fossil diesel and BTL diesel.

	Chemical formulae	Sulphur (ppm)	LHV (MJ/kg)	Density (kg/l)	Cetane number	Flash point (°C)	Cloud point (°C)
Fossil diesel	C15–C20	10–50	41.8–43	0.82–0.84	45–53	51.5–65	−45 to −50
BTL diesel	C12–C20	0–3.5	42.9–44	0.77–0.78	70–80	58.5	−20

Sources: [9,24].

Table 3
Energy expended to produce diesel (MJ_{ex}/MJ_{fuel}).

Diesel from lignocellulosic waste		Diesel from farmed wood		Diesel from crude oil	
Waste collection and chipping	0.06	Wood farming and chipping	0.09	Crude oil extraction and processing	0.03
Transport	0.04	Transport	0.01	Transport	0.01
Gasifier and FT plant	1.08	Gasifier and FT plant	1.08	Refining	0.10
Diesel distribution and dispensing	0.02	Diesel distribution and dispensing	0.02	Diesel distribution and dispensing	0.02
Total pathway	1.19		1.19		0.16

Source: [27].

others (i.e., pre-treatment of feedstock, distribution), and only a small portion of energy is used in the transport stage.

As for the material balance, the conversion efficiency range of 16–18% is low; that is, from 1000 kg of raw biomass, only 13 kg–16 kg of FT diesel can be extracted.

3. Methodology

To estimate the production of BTL diesel from residual biomass, it is necessary to evaluate the energy potential of these residues found in the Apulia territory. For this, a qualitative evaluation was initially performed, identifying crops most suitable for our aim. For each crop, the residues generated have been specified and included in the following quantitative estimate.

For calculating the amount of residues for each type of crop and for each Apulia province, the methodology used is illustrated below [28–30], based on a linear correlation among some parameters. In particular, the estimate is made on the basis of main output per year using statistical data [31]; using a reproducibility factor of residues, taking into account the real availability of same residues, net of the share of residues already been utilized. Two types of residues have been considered: a main residue (R1) that is produced per year, and a secondary one (R2) that is generated after several years of cultivation.

The ratio between residue and production of the main output (R1/P) holds special relevance in that it represents the quantity of residues per output unit. This ratio is highly variable owing to the type of crop, production and harvest techniques, and other factors.

We emphasise that the total production per crop (P) per year is greatly influenced by several factors, first of all by climatic conditions. For this reason, an average value of P has been calculated, considering the range of years 2006–2009. This average is calculated per crop and per each Apulia province. The same has been made for the estimate of production area (PA) per crop and per each Apulia province. Input and output data are the following:

Input data (see Table 4)

- production area (ha), PA,
- production of the main output (t), P,
- ratio of residue/main output, R1/P,
- potential availability factor of residue (%), AR1,
- wet basis moisture content of residue (%), WR1,
- time for generating residues of cultivation (y), TR1,

For arboreal crops, the following have also been estimated:

- production of secondary residues (t/ha), PR2,
- potential availability factor of residue (%), AR2,
- wet basis moisture content of wood from uprooting (%), WR2,
- time for generating residues of cultivation (y), TR2.

Output data

- Mass of main residues (t), M_{R1},
- Mass of secondary residues (t) M_{R2}.

The following are conversion equations used:

$$\text{(Eq. 1) Mass of the main residues } (t): \ M_{R1} = P(R1/P)\left[\frac{(1-WR1/100)}{TR1}\right]\cdot\left(\frac{AR1}{100}\right)$$

$$\text{(Eq. 2) Mass of the secondary residues } (t): \ M_{R2} = PR2\ PA\left[\frac{(1-WR2/100)}{TR2}\right]\cdot\left(\frac{AR2}{100}\right)$$

We underline that for calculating the mass of R1 of some arboreal crops, a specific correlation is necessary, illustrated in the note of Table 4.

On the basis of the quantity of residues previously calculated and considering the low heating value (LHV) for each residue, the energy potential of agro-forest residues in Apulia per year and their possible use for supplying the regional diesel production chain have been estimated. Moreover, taking into account the feedstock availability in each provincial area, it has been possible to identify the most appropriate potential location of a BTL diesel plant in the Apulia region, considering a gathering area with a radius of up to 50 km, which is compatible with a short production chain.

Table 4
Utilized factors for the estimate of residues.

Factors	Wheat	Barley	Oats	Olive tree	Vine	Almond
R1/P	0.70	0.80	0.70	*a**	*b**	1.9
AR1 (%)	65	65	65	80	80	60
WR1 (%)	15	15	15	30	30	25
TR1 (y)	1	1	1	3	1	2
PR2 (t/ha)	–	–	–	–	22	30
AR2 (%)	–	–	–	–	95	85
WR2 (%)	–	–	–	–	20	20
TR2 (y)	–	–	–	–	25	30

Sources: [29,30].
*a, b. In the case of olive tree and vine there is a specific correlation between the yield of R1 and the yield of P, represented by the following equations:
(a) R1 yield (t/ha) = 0.113·grape yield (t/ha) + 2.0.
(b) R1 yield (t/ha) = 0.566·olive yield (t/ha) + 1.496 (Foggia and Bari provinces).
R1 yield (t/ha) = 0.305·olive yield (t/ha) + 1.401 (Taranto, Brindisi, and Lecce provinces).
The differing correlations among Apulia provinces is due to different times of pruning.

4. Case study: the potential of local residual biomass

The conversion models shown in the previous section are applied to Apulia data with the first aim being to estimate the availability of residual biomass in this region. In the utilized agricultural area (UAA), which is 90.6% of the entire agricultural land in Apulia, cereals are the most widespread crop (about 32%), followed by olives (25%), permanent grass crops (10.8%), vines (10.6%), temporary grass crops (7.5%), vegetables (7%), fruits (3.7%), no-food crops (1.3%), and citrus trees (0.8%). The main herbaceous crops (being wheat, barley, and oats) and arboreal ones (olive trees, vines, and almond) have been taken into consideration [32]. For each crop, a

Table 5
Main and secondary residues per crop considered.

Crop	Product	Main residues (R1)	Secondary residues (R2)
Herbaceous			
Wheat	Caryopsis	Straw	–
Barley	Caryopsis	Straw	–
Oats	Caryopsis	Straw	–
Arboreal			
Olive tree	Drupe	Leafy and branch pruning	–
Vine	Grape	Shoots	Wood from uprooting
Almond	Drupe	Branch pruning	Wood from uprooting

Sources: [29,30].

specific residue is identified (see Table 5). In particular, the main residues considered are:

- herbaceous residue: the straw only;
- arboreal residues: vine shoots, leafy and branch pruning of the olive tree, branch pruning of the almond.

The secondary arboreal residues are wood from vine uprooting and almond.

By applying conversion equations (1) and (2), and on the basis of the data from Tables 6 and 7 concerning the average value of P and PA per province, M_{R1} and M_{R2} can be calculated. The amount of lignocellulosic residues at the provincial level is the sum of M_{R1} and M_{R2} per each residue, per crops and province (see Table 8).

Table 9 illustrates that the Foggia provincial area has the most quantity of residues (mostly herbaceous), whereas in other areas, arboreal residues outnumber the rest. Certainly, a useful indicator is the territorial density of the residues, because their territorial dispersion represents a weak aspect of the production chain of biofuels from lignocellulosic residues (as already mentioned). By considering the territorial density of the residues with regard to the total provincial area (Table 9), it emerges that the highest figure is of the provincial area of Foggia, with 73.5 t/y/km^2, followed by Taranto (62.0 t/y/km^2), Bari (57.4 t/y/km^2), Brindisi (49.2 t/y/km^2), and Lecce (34.2 t/y/km^2). The total for the Apulia region is 59.8 t/y/km^2, with shared quantities of herbaceous and arboreal crop residues.

Table 10 summarizes the figures for the whole region. The regional estimated total is 1,159,078 t/y, of which around 54% are arboreal residues and 46% are herbaceous. The forest residues coming from broad-leaf and resinous high tree and coppices, even if these are in small quantities (6342 t/y), need to be added to this amount. Therefore, the grand total is over 1,165,420 t/y.

4.1. Diesel production in Apulia from inland residues

All these residues could be suitable as an energy production input, applying different processes with regard to their particular characteristics (mainly low heating value [LHV] and moisture). However, their use as an input for the diesel production chain has been only analysed in this paper.

On the basis of previous data, the energy potential of agro-forest residues in Apulia per year has been estimated, as shown in Table 10. The grand total for the amount of residues from crops considered is 20,456 TJ/y.

Considering an energy efficiency of 40–45% for the production of BTL diesel and its LHV of 44 GJ/t (34 GJ/m^3), about 20,000 TJ of energy embodied in biomass is converted into 182,000 to 204,000 t (193,000 t on average) of BTL diesel, equal to 8000 TJ to 9000 TJ. This is in agreement with the mass conversion efficiency of 16–18%, as has been mentioned in Section 2.1. To the quantity of 193,000 t of BTL diesel, the following have additionally been added: (a) about 450 t of biodiesel from waste cooking oil produced in Apulia[2]; and (b) the amount of biodiesel from dedicated energy crops (such as sunflower), equal to around 20,000 t. The latter quantity has been estimated in a previous paper, which analysed the biodiesel generated by energy crops cultivated in the set-aside land of Apulia [33].

The total amount of biodiesel possible that can be produced in Apulia from these three sources amounts to over 213,000 t. If we consider the current diesel consumption in Apulia (i.e., 1,300,000 t per year), we estimate that approximately 16% of this quantity can be substituted by diesel produced from inland biomass.

4.1.1. Greenhouse gas savings

The substitution of an equal share of fossil diesel with BTL diesel could have a positive effect from an environmental point of view as well, particularly with regard to greenhouse gas (GHG) emissions. The European Directive 2009/28/EC, Part B of the V Annex, describes the GHG emissions' savings of the Fischer–Tropsch diesel from waste wood and from farmed wood, and the savings from sunflower biodiesel. These have been compared with fossil diesel GHG emissions. The estimations of these GHG savings have been calculated according to the methodology contained in Part C of the same annex: assuming that the greenhouse gas emissions from fuels, E, are expressed in terms of grams of CO_2 equivalent per MJ of fuel (g CO_{2eq}[3]/MJ [2]), the savings shall be calculated as $(E_f - E_b)/E_F$, where

E_b = total emissions, from production to use, of the biofuel or other bio-liquids (where FT diesel from waste wood is 4 g CO_{2eq}/MJ, FT diesel from farmed wood is 6 g CO_{2eq}/MJ, and biodiesel from sunflower is 41 g CO_{2eq}/MJ);
E_f = total emissions, from production to use, of the fossil fuel comparator (where fossil diesel is 83.8 g CO_{2eq}/MJ).

Table 6
Production area (ha/year) and production (t/year) per herbaceous crops per province in Apulia. Average of years 2006–2009.

Provinces[a]	Wheat		Barley		Oat	
	PA	P	PA	P	PA	P
Foggia	222.300	624.150	7.475	24.363	22.025	67.370
Bari	54.532	154.502	17.637	52.490	4.102	12.293
Taranto	29.269	61.686	3.387	8.263	2.775	6.420
Brindisi	19.737	40.586	1.737	2.739	3.087	4.866
Lecce	28.000	41.550	4.350	7.185	4.825	7.738

Source: Personal elaboration on data [31].
[a] Since June 2009 the number of Apulia provinces is six. In our analysis data of the new province are included in the Bari province figures.

[2] With regard to Apulia, over 2.6 thousand t of waste cooking oil is generated each year. Less than 50% of the production, about 1.25 thousand t, has been collected separately; then after regeneration, 0.450 thousand t are processed into biodiesel.
[3] The green house gases taken into account shall be valued as follows: CO_2: 1; N_2O: 296; CH_4: 23.

Table 7
Production area (ha/year) and production (t/year) per arboreal crops per province in Apulia. Average of years 2006–2009.

Provinces	Olive tree		Grape		Almond	
	PA	P	PA	P	PA	P
Foggia	54.825	154.868	41.992	645.875	1.500	3.075
Bari	129.100	412.545	37.028	605.372	20.250	22.593
Taranto	37.975	113.290	39.550	519.291	632	1.329
Brindisi	63.000	166.950	16.525	163.401	5.800	4.730
Lecce	88.635	318.121	13.237	110.138	79	565

Source: Personal elaboration on data [31].

Table 8
Availability of lignocellulosic residues in Apulia provincial area (tons per year, dry substance)[a].

Crop	Foggia, t/y	Bari, t/y	Taranto, t/y	Brindisi, t/y	Lecce, t/y
Wheat	341,390	59,754	23,857	15,697	16,069
Barley	10,768	23,201	3,652	1,211	3,176
Oat	26,055	4,754	2,483	1,882	2,993
Herbaceous crops total	*378,213*	*87,709*	*29,992*	*18,790*	*22,238*
Olive tree	31,725	79,767	16,375	25,990	41,198
Vine	116,032	104,596	103,526	39,924	30,647
Almond	2,291	22,956	979	5,840	290
Arboreal crops total	*150,048*	*207,319*	*120,880*	*71,754*	*72,135*
Short rotation forestry	18,576	4,867	4,241	487	454
Residues	4,133	1,068	932	107	102
Forest residues total	*22,709*	*5,935*	*5,173*	*594*	*556*

Source: Personal elaboration on data [29–31].
[a] This is the sum of M_{R1} and M_{R2} per each residue, per crops and province.

Table 9
Territorial availability and density of lignocellulosic residues in Apulia.

Provincial area	Crop residues (t/y)		Territorial surface (km^2)	Density of crop residues (t/y/km^2)
	a		b	c = a/b
Foggia	Herbaceous	378,213	7,192	52.6
	Arboreal	150,048		20.9
Total				73.5
Bari	Herbaceous	87,709	5,138	17.1
	Arboreal	207,319		40.3
Total				57.4
Taranto	Herbaceous	29,992	2,429	12.3
	Arboreal	120,880		49.7
Total				62.0
Brindisi	Herbaceous	18,790	1,839	10.2
	Arboreal	71,754		39.0
Total				49.2
Lecce	Herbaceous	22,238	2,759	8.1
	Arboreal	72,135		26.1
Total				34.2
Apulia	Herbaceous	536,942	19,358	27.7
	Arboreal	622,136		32.1
Total				59.8

Source: Personal elaboration on data [30,31].

Table 10
Availability of lignocellulosic residues in Apulia and their energy potential per year.

Crop	Crop residue availability (t/y) d.s.	LHV (GJ/t)	Energy potential (TJ/y)
Wheat	456,767	17.5	7,993
Barley	42,008	17.5	735
Oat	38,167	17.5	668
Herbaceous crops total	*536,942*		
Olive tree	195,055	17.6	3,433
Vine	394,725	17.5	6,908
Almond	32,356	18.6	602
Arboreal crops total	*622,136*		
Total	*1,159,078*		
Forest residues total	*6,342*	19	120.5
Grand total	*1,165,420*		20,456.5

Source: Personal elaboration.

Fig. 2. Apulia map and suitable BTL plant localization.

According to the previous data, the savings are 95% and 93% for the FT diesel from waste wood and from farmed wood, respectively, and 51% for biodiesel from sunflower.

On the basis of fuels produced and used in Apulia, it has been estimated that the GHG emissions related to 213,000 t of diesel from residual biomass are over 64,000 t CO_{2eq} [4], instead of around 767,000 t CO_{2eq} from 213,000 t of fossil diesel. This calculates to a savings of 703,000 t CO_{2eq}, and in this case the regional emissions regarding diesel consumption could drop to 3981,000 t CO_{2eq} instead of the current 4684,000 t CO_{2eq}. This reduction could be an overall environmental benefit for the region, which is affected by the highest per-capita value of CO_2 in Italy (around 15 t/y/in. in Apulia against the Italian average of 8 t/y/in.). This is due to electricity production from fossil fuels (particularly coal), and to the massive steel production within the Apulia region.

5. Results and discussion

In order to formulate a hypothesis concerning the launch of new production chains for diesel from residual biomass on a regional scale [34], coupled with feedstock availability in each provincial area, a gathering area (7850 km^2) with a radius of up to 50 km has been considered. This hypothesis aims to minimize the economic and environmental costs. The most appropriate location of a BTL plant in Apulia could be the territory between Foggia and Bari (see Fig. 2), considering that these provinces have 73% of the total amount of residual biomass (approximately 851,933 t/y) for Apulia (Table 9), and are also characterized by a high density of crop residues.

The proposed plant is projected to handle power of 220 MW (1 MW = 655 t/y FT diesel) [35] and process approximately 800,000 t of biomass per year with the purpose of producing 144,000 t/y of FT diesel. The capital investment costs usually reported in the short term are in the range of 2500–2800 €/$kW_{FT\ diesel}$, hence the total cost of the BTL plant should be between 550 M€ and 616 M€ [36]. After the start-up phase of the plan, utilizing residues from provinces located out of the 50-km-radius gathering area could be considered, along with suitable locations for pre-treatment facilities. The aims of pre-treatment are to reduce the residue size and to minimize transport costs, which are usually very high owing to the low density of this type of biomass. In particular, this concept could be implemented in the province of Taranto, because of its considerable amount of residues, characterized by a high density.

We note, however, that to obtain the highest profitability, the optimal scale for the BTL plant is higher than the scale of our hypothesis. We emphasise that the decrease in investment costs due to the increase in plant size is much more significant than the increase in transport costs [37,38]. As a consequence, in the case of our region, in the medium term the BTL plant should plan for an implementation of production units in order to optimize its scale [39]. This increase in scale could be obtained through the use of residual biomass collected, as above, from the other provinces of Apulia and within nearby regions.

[4] The total amount of 64,000 t CO_{2eq} is the sum of approximately 34,000 t CO_{2eq} that comes from 193,000 t of FT diesel (taking into account the emissions of 4 gCO_{2eq}/MJ of waste wood) and 30,340 t CO_{2eq} from 20,000 t of biodiesel.

The establishment of a second-generation biofuel production plant could become a strategic flywheel for regional development, and an important competitive advantage at the national level at the least, owing to the perspective of worldwide growth. The final result could be a further progression of Apulia as the leading Italian region in the renewable energy sources sector. This role is also confirmed by the supremacy of installed wind and photovoltaic power plants achieved in 2009 (946 MW, equal to 25%, and 56.5 MW, equal to 13%, respectively, of the Italian total).

One of the main constraints for wider utilization of renewable resources is their poor profitability. Biofuel production costs are influenced by several drivers, such as maturity of technology, therefore differing widely. Currently, some biofuel products are already competitive in the marketplace, even though most are promoted by incentives or regulations, and will only be truly competitive in an environment of higher oil prices. The bioenergy costs are strictly linked to the prices of biomass resources—in fact, in most cases, around 50% of the entire cost is determined by the raw materials (biomass) [40]. As a consequence, biofuels are much more sensitive to the price of agricultural feedstock than food products, in which the entire production cost, in many cases, is less than 10% as determined by the prices of agricultural goods [16]. This is especially true for first-generation biofuels based on traditional crops, rather than for the new cropping systems, such as BTL diesel from lignocellulosic biomass or residues, for which there are greater expectations of cost reduction in the medium- and long-term [41,42].

Nowadays, the cost of BTL diesel generation by conventional techniques is around 22 €/GJ, or 0.75 €/L to 0.66 €/L. The IEA costs forecast predicts a reduction to 14–17.6 €/GJ in 2020, and 11.7–14.7 €/GJ in 2050 [41]. The economies of scale, technological innovations, and newly selected catalysts are the main sources for cost reductions.

Considering the industrial price of fossil diesel, which at present is around 14.7 €/GJ, a policy of incentives and support to production and sales of these new fuels will be necessary, at least in the start-up phase, as has been previously mentioned. We underline that an overall harmonisation of regulations regarding incentives and tax reductions across the EU, as well as the introduction of sustainability certification schemes (in view of avoiding market distortion and unfair competition), are very important. In addition, biofuel development is strongly aligned with the CAP (Common Agricultural Policy) and Forestry policies, and a coherent policy framework will be very useful, as underlined in the EU Biomass Action Plan.

Better communication with the public on the positive effects of production and use of biofuels, and a greater sense of public opinion will ensure a wider social acceptance, as provided by the new European legislation [1]. For instance, the positive effects regarding land use competition should be stressed. The yield per hectare of second-generation biofuels is a positive aspect for boosting their implementation. At present, the feasible land availability for woody and herbaceous biomass appears to be larger than for agricultural feedstock and, moreover, the BTL biofuels yield per hectare is larger than that of conventional biofuels (especially biodiesel). The worldwide yield for BTL diesel can be estimated at around 4 t/ha on a land surface of 118 Mha, foreseen in 2050.

6. Conclusions

The development of a BTL diesel chain obtained by a combination of the two technologies (gasification and FT synthesis) makes the production system much more complex than first-generation biofuel plants, both from an environmental and economic point of view [12]. Demonstration plants at a relevant industrial scale are needed in order to acquire feedback, and to validate the costs and technical performance, but unfortunately this is often capital-intensive.

Moreover, at the regional level, potential risks due to lack of skilled workers and specific technological expertise have also been taken into account. These, together with the non-participation of local enterprises, could promote the undesirable use of labour and equipment from abroad [43].

A strong cross-sector coordination between biomass suppliers (agriculture and forestry sectors), fuel industry participants, and car manufactures is essential, because the biomass energy sector involves many stakeholders with differing points of view and expectations.

In conclusion, it is imperative that local governments (e.g., at the regional level) initiate actions in order to innovate their production systems and implement second-generation biofuel technology. This innovation should also involve the planning of a complex and integrated system to convert agricultural activities into an agro-energy district.

The results of our analysis illustrate that the dimension of this district can be identified within the Apulia region, but we stress that it may be necessary for a territorial enlargement of regions nearby, in order to gather much more feedstock and to construct a more profitable second-generation biofuel chain. This latter comment poses an opportunity for common actions among regional governments.

Acknowledgements

This work is the result of the authors' commitment, beginning with the idea and ending with this accomplishment. Particularly, Sections 1, 2, 3, 4, and the reference collection are ascribed to A. Paiano, the sub-Section 1.1 is ascribed to G. Camaggio, and Sections 5, 6, and the reference collection to G. Lagioia.

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